

Challenging Issues in Inter-Satellite Optical Wireless Systems (IsOWC) and its Mitigation Techniques

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Abstract— Inter-satellite optical wireless communication system (IsOWC), one of the important applications of FSO (Free Space Optics) technology, will be deployed in space in the near future because of providing power efficient and high bandwidth allocation facilities unlike present microwave satellite systems. In this paper, we have deliberated a presentation of different challenging issues in achieving a prolonged inter satellite link for an IsOWC system under different situations and conditions. This work is also emphasized on the suggested techniques to combat with the degrading factors to put into practice of high speed IsOWC system with minimum BER.

Index Terms— Inter-satellite optical wireless system (IsOWC), BER, SNR.

I. INTRODUCTION

From prolonged fibers to wireless systems, optical systems had been transformed into hybrid optical wireless communication system to be used even in space communication applications. Use of laser technology in communication makes the possibility of transmitting information at high data rates with coverage of thousands of kilometers. Due to this, optical wireless communication had been adapted into space technology and hence inter-satellite optical wireless communication (IsOWC) came into being [1]. An IsOWC system offers a high bandwidth, small size, low power and low cost compared to microwave satellite systems [2]. In addition, lasers exhibit narrow beam-width compared to RF systems which results in lower loss than RF. The basic configuration of IsOWC technology involves two satellites acting as transmitter and receiver while free space acts as propagation channels to transmit light signals. A highly accurate tracking system is required which involves the use of beacon signal on one side and a quadrant detector with tracking system at other satellite which ensures that the connecting satellites are aligned and have proper line of sight [3].

IsOWC technology is used for connecting one satellite to another, whether the satellite is in the same orbit or in different orbits. Inter-satellite links had been employed on several satellite systems, such as Iridium and NASA's tracking and data relay satellite system (TDRSS), where RF is used to link the satellites. Several satellites have been developed with OWC inter-satellite links such as European Space Agency (ESA)'s Artemis and Japan's Kirari satellites [4]. The first inter-satellite optical link communication was successfully achieved on March 2003 between Artemis and French satellite

named SPOT-4. Artemis was placed in the GEO satellite while SPOT-4 was in LEO at an altitude of 832 km [5]. But, still there is a need of increasing the high speed ISL links for such hybrid systems. This work emphasizes on the challenging issues of high speed long spanned IsOWC system that limit its performance and the remedies to achieve minimum BER at minimum transmitted power levels with prolonged ISL links.

II. DEGRADING FACTORS AND ITS MITIGATION TECHNIQUES

Although, IsOWC is a better technology for transmission of data at high rates but various parameters (tracking noise and vibrations) should be taken into account which limit the system performance [6]. The tracking system suffers from various noise sources such as laser relative intensity noise (RIN), Johnson noise, dark current shot noise, signal shot noise, and background shot noise. But, vibration noise is the most dominated degrading factors of IsOWC communication system. When signal from TT&C system enters the control system, it points the transceiver to the other satellite. These noises from the control system are added to the pointing signal which causes vibration of the pointing direction. Due to vibrations of the transmitter beam to the receiver satellite, the misalignment between transmitter and receiver occurs, which degrade the system performance. The simplest expression for tracking noise is mathematically expressed as [7].

$$\sigma = [SF(SNR)^{0.5}]^{-1} \quad (1)$$

Where, SF is the angular slope factor expressed in units per radian and SNR is the signal to noise ratio. The performance of the TT&C system is also greatly affected by background radiations and mechanical vibrations due to interstellar objects and continuous movement of the satellites [8-9]. In-homogeneities of gravitational force through the satellite orbit are also responsible for vibrations. Internal noise comes into picture because of waveguide switch solar array drive mechanism, antenna pointing mechanism and gyroscope [10]. In IsOWC systems, the main focus is to dissipate minimum power and to obtain a minimum BER. The vibrations of the transmitted beam cause decrease in the received signal strength at receiving end which further increases the BER. Some other problems related to the satellite vibrations include deviation from the line of sight, misalignment between the transmitter and the receiver scheme and signal attenuation [11-12]. Several solutions had been proposed for compensating the vibration effects which degrade the link

performance. SNR is the basic parameter that affects the performance of any communication system. Because of vibrations, the decrease in received signal causes the SNR to decrease which tends to increase BER. This problem is overcome by either increasing the transmitted power or decreasing the receiver noise. But, with the increase of power, a number of other problems like high energy consumption, large weight accompanied due to big size of the satellite, high cost and complexity in system arises. The basic solution is to adapt the bandwidth and the receiver parameters to change due to transmitter vibrations to cause a decrease in noise power [13-14]. Fig. 1 shows the adaptive bandwidth of the inter-satellite system as the function of vibration amplitude with different power levels.

To obtain minimal BER or acceptable SNR, there is another parameter i.e. transmitter divergence angles play an important role in such systems. It had been observed that small transmitter divergence angles are used to assure maximum received power which eliminates the problem of power dissipation with minimum BER. The optimum value of the received power as a function of the pointing vibration displacement determines the optimum beam divergence angle or transmitter gain.

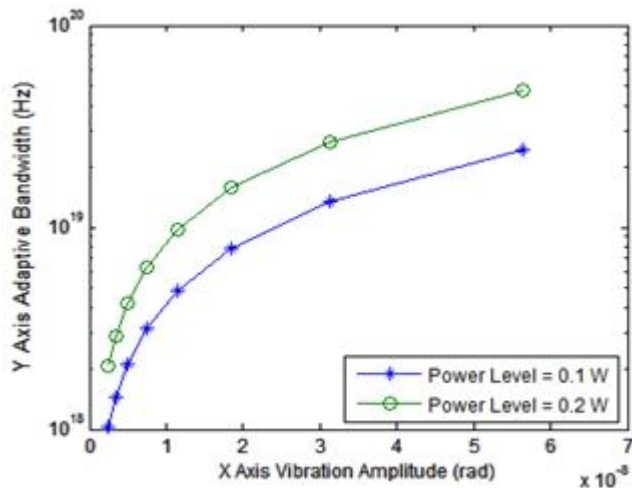


Fig. 1. Adaptive system bandwidth as a function of vibration amplitude at different transmitted powers.

The implementation of this adaptive model in satellite optical communication includes two subsystems: a vibration amplitude measurement unit and an adaptive variable telescope gain. If the vibration amplitude measurement unit senses any change in vibration amplitude, it adapts the telescope gain to optimum values in order to maximize the performance of the communication system for the new vibration level. In this method, the gain of the transmitter is changed using phased array techniques [15]. A phased array telescope is composed of several radiating elements. By feeding the proper phase and amplitude differences to the radiant elements, the array radiation pattern can be shaped as needed for minimum BER. But, due to use of very narrow beams, the transmitter sometimes may miss the receiver satellite due to pointing vibrations. Therefore, for small divergence angles, the transmitter optics aperture needs to be kept large

which further increasing the cost [16]. Further, to deal with the problem of scintillation of received power, large link power margin is required to be supplied so that even if the received power scintillates, BER matches the requirement. But, this solution has a number of disadvantages like high average energy consumption and heat transfer problems. A different solution for this problem is the adaptation of the transmitter power to the vibration amplitude [17]. In this remedy, the computer transfers the information to the power controller that adapts the transmitter power to the value required in order to keep low BER. Another situation is created when the computer intends to operate one of the subsystems that cause high values of vibration. Before the operation, the computer informs the power controller of the expected operation. The power controller adapts the laser transmitter to this situation.

Further, to reduce the error probability of such systems, many coding techniques are also being used such as Block-, Reed-Solomon- and convolution- coding [18]. Both ARQ and FEC can also be used to improve the BER of such communication systems. But, sometimes coding techniques may yield lower performance as compared to un-coded ones in the condition of achieving low SNR below the code threshold. But, the error probability can be reduced when the information rates smaller than the channel capacity.

To achieve minimum BER in such systems at minimum transmitted power, the channel quality is also one of the dominating issues. To improve channel quality, diversity technique is used, which employs a number of independent propagation paths for transmitting the same information. This method is used when the quality of the channel changes drastically in a random manner. Using a number of channels increases the probability that at least one channel will be of sufficient quality in each time slot. Satellite communication networks are like meshes around the globe, so that every two points can connect via many different routes. Therefore, if one route is strikebound due to vibration of one satellite in the path, the information can propagate through other paths to the destination. Fig 2 shows the variation in adaptive

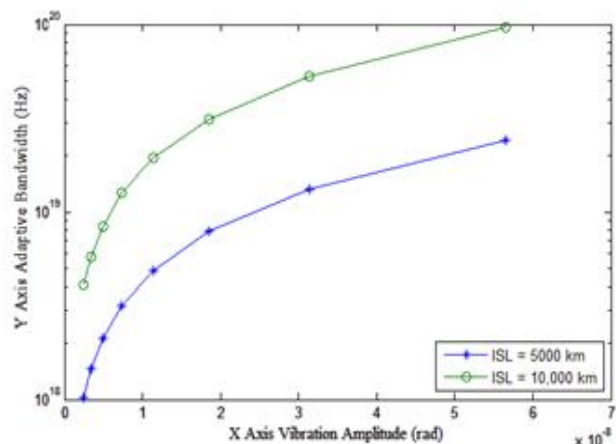


Fig. 2. Adaptive system bandwidth as a function of vibration amplitude at different Inter satellite link range (ISL)

system bandwidth as a function of vibration amplitude at different ISL ranges. Deployment of vibration-isolator (active

or passive) is also an attractive and effective technique to reduce the signal vibrations in inter-satellite communication. It reduces the transmission of vibrations from the spacecraft body to the communication system [19]. The passive isolator is designed to reduce the vibration disturbances in the high frequency region but its ability of disturbance rejection of the fine pointing mechanism is not sufficient. So, an active isolator is a better option to diminish low-frequency and high amplitude vibrations.

CONCLUSIONS

Depending upon the discussion in previous sections, it is concluded that the satellite vibrations is the major challenging issue to make implementation of high speed IsOWC feasible. Due to satellite vibrations, the misalignment occurs between transmitter and receiver which degrade system performance. The basic solution is to adapt the bandwidth and different receiver parameters to cause an increase in SNR which helps in achieving minimum BER. Further, due to use of very narrow beams, the transmitter may sometimes miss the receiver satellite due to pointing vibrations. So, it is recommended to use small divergence angles, which further require large and costly transmitter optics aperture. Different coding-, modulation-and diversity-techniques like OFDM are recommended to realize the implementation of high speed IsOWC transmission system with acceptable SNR at minimum BER with less transmitted power in conjunction with prolonged ISL links.

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